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Costs to the Public Due to Use of Corrosive Deicing Chemicals and a Comparison to Alternate Winter Road Maintenance Procedures

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COSTS TO THE PUBLIC DUE TO THE USE OF
CORROSIVE DEICING CHEMICALS AND A
COMPARISON TO ALTERNATE WINTER
ROAD MAINTENANCE PROCEDURES

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IMPLEMENTATION STATEMENT

With regard to the use of deicing chemicals for their winter maintenance programs, all levels of government in Alaska routinely only consider the direct program costs (of materials, equipment, and labor) during their budgetary process, basically because these are the costs that traditionally have been quantifiable and administratively recognized. But in reality, the total program costs (including the indirect costs of corrosion damage to vehicles and facilities) end up being borne by the public so consideration of the overall picture would seem more appropriate.

This report examined all the costs of the current deicing programs for the Anchorage area and then presents feasible alternatives for reducing the total costs of the programs. From the information derived in this study, it becomes apparent that the lowest direct costs for the use of deicing chemicals in a winter maintenance program do not result in the lowest total costs to the public. However, since all direct costs come straight from government coffers while some of the indirect costs are incurred over the long-term by individual members of the general public (these are incrementally small amounts but collectively large), the situation is not that simple. The public (also the legislative and executive branches of government) has a general desire that maintenance expenditures be minimized, and in this case the more frugal approach would require increased short-term government spending for winter maintenance. For the implementation of these research findings, therefore, the public's attitude first must necessarily be changed through education about and awareness of corrosion damage such that they perceive that their cost burden can be reduced without restricting this winter maintenance expenditure. A major policy change would then be mandated.

Within the Department of Transportation and Public Facilities the following prioritized actions are required for the orderly accomplishment of reducing indirect costs based on this total costs concept:

1. Begin to build and use sand storage facilities in order to maintain unfrozen sand stockpiles. (This could eliminate about 85% of total salt usage statewide.)
2. Examine alternate deicing agents (evaluation of CMA falls in this category).
3. Calibrate distribution equipment and optimize deicing chemical application rate for effectiveness.
4. Train maintenance managers and operators on proper application techniques for specific weather conditions.
5. Develop standard maintenance policies which outline procedures to be followed in various weather conditions, including set application rates.

Priority 1 necessitates an adoption of new policies in order to plan for funding, programming, design, construction, maintenance, and operation of such facilities. Priorities 2 and 3 are the responsibility of the Research Section to pursue through to fruition in a timely fashion. And once those priorities have been attained, 4 and 5 would involve tasks accomplished by Maintenance and Operations for the final implementation of all facets presented.

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SUMMARY

The salts sodium chloride (NaCl) and calcium chloride (CaCl_2) are currently employed on a widespread basis to minimize icy winter road conditions. When based strictly on cost/effectiveness per unit material, sodium chloride is an obvious choice for roadway deicing use; however, when costs of salt related damage are included, the total cost of salt use is drastically increased. The negative effects of salts include corrosion of ferrous metals and related concrete spalling, stunted growth or death of roadside vegetation, and increased chloride levels in water supplies which pose a potential health problem.

This study is a pragmatic attempt to quantify salt related damage to vehicles and bridge decks in the Anchorage area and to examine possible means of reducing the use of salt. Total cost as used in this report includes direct materials costs and indirect costs of loss of vehicle value and damage to bridge decks.

Corrosion damage to vehicles in the study area is estimated at \$5.1 million per year, and repair costs for corrosion damage to bridge decks are approximately \$68,000 per year. Considering these damages as part of the total costs of salt usage makes the use of less damaging alternatives, with higher initial costs, more feasible. Use of alternative chemicals and heated sand storage buildings were examined in the economic analysis. By storing sand in heated buildings, approximately 85% of NaCl use could be eliminated.

<u>Program</u>	<u>Total Program Cost</u>
A) NaCl , CaCl_2 , Sand	\$ 5,878,000/yr.
B) CMA, Urea, Sand	\$ 2,437,000/yr.
C) Heated Sand Storage Buildings, NaCl , CaCl_2	\$ 1,399,200/yr.
D) Heated Sand Storage Buildings, CMA, Urea	\$ 872,000/yr.

The amount of corrosion damage to a particular vehicle depends upon many factors such as design, maintenance, driving conditions, and climate, but the average vehicle owner in the Anchorage area can expect to pay approximately \$3,000 to restore a 5 or 6 year old car to near-new appearance. This cost represents repairs needed due solely to corrosion damage. Value loss is estimated to be approximately 50% of repair costs. Utilizing predictions of vehicle population growth in the Anchorage area, salt induced corrosion could cause vehicle value losses of \$6.5 million/yr. by the year 1990 and \$8 million/yr. by year 2000, if current maintenance practices continue.

All of these costs are borne by the public - through reduced vehicle value or through increased State expenditures. Changes to maintenance procedures will have to come as a policy decision, and a first step towards change is recognition of the real total cost of salt use. The magnitude of salt damage costs indicates that efforts to reduce salt use are justifiable, even if higher first costs are incurred. Identified methods for reduction of salt use include utilizing heated sand storage buildings, formulating specific chemical application rates, calibration of distribution equipment, specific policy decisions regarding winter road maintenance, and continued research into alternate chemicals.

1.0 INTRODUCTION AND SCOPE OF RESEARCH

Over the past 30 years, Americans have become accustomed to clean, bare roads throughout all seasons of the year. This policy of "bare-roads" has led to an ever increasing use of salt to minimize icy winter road conditions. As both the number of vehicles and miles of road increase, we are assured of an even greater dependence on salt in the future.

Generally, the direct costs of a deicing program include the purchase of maintenance materials and their storage and distribution. With the use of corrosive deicing chemicals, most commonly the salts sodium chloride (NaCl) and calcium chloride (CaCl_2), costs of related damage should also be included. Salt induced corrosion affects not only vehicles utilizing the roadway, but also critical elements of the roadway itself; bridge, ramp, and overpass structures are particularly vulnerable due to their construction. Although typically not considered as part of the costs of a deicing program, repairs to bridge decks and reduction of vehicle value are real costs to the public resulting from the use of corrosive deicing chemicals. Additional costs, even more difficult to quantify, are damage to the roadside environments and to the quality of surface and groundwaters.

Occurrence of salt related damage is generally recognized, but the amount and severity of that damage is not well known. A report issued in 1976 by the U.S. Environmental Protection Agency placed the total annual national cost of salt related damage at a minimum of \$3 billion dollars, or approximately 15 times the annual national cost for salt purchase and application.¹ The \$3 billion dollar cost represents a national average and is lower than the cost incurred in specific areas of high salt usage. That report studied damage to water supplies and health, vegetation, highway structures, vehicles, and utilities. The highest damage costs were found to involve vehicles and bridges. While elements in these two categories can be replaced, the cost is borne by the public in either instance. When informed of these hidden, indirect costs of salt use, the public is very likely to elect to reduce this total cost. In a number of Eastern seaboard states, an informed public has been willing to bear increased initial costs to reduce salt related damages. The higher initial costs, incurred through various efforts to reduce the

amount of salts used, result in an overall savings when the damaging effects of salts are quantified and added to the direct program costs.

When based strictly on cost/effectiveness per unit material, sodium chloride is an obvious choice for roadway deicing use. Because of the known harmful effects of NaCl, researchers have tested and identified substitute chemicals which can operate efficiently with fewer harmful effects; however, the identified alternatives have either higher materials costs or require greater application rates, so sodium chloride has continued to be seen as the most economical choice. When examined in terms of total cost however, salt no longer presents such a rosy picture.

This paper represents a pragmatic attempt to quantify salt related damage to vehicles and bridges in the Anchorage area and to examine possible means of reducing the use of salt. Total program cost as used in this report includes direct and initial costs and indirect costs of loss of vehicle value and damage to bridge decks. Two major avenues examined for reducing the total costs of the present Anchorage deicing program are: 1) utilize heated storage buildings for stockpiling sand and 2) replace salt with non-corrosive deicing chemicals. These options were selected based on simplicity, feasibility for the study area, and production of results similar to current maintenance procedures.

2.0 ELEMENTS OF WINTER ROAD MAINTENANCE

Before outlining specific deicing policies, a brief introduction to the elements of winter road maintenance will be helpful in examining current maintenance and potential alternatives in the Anchorage area. Winter road maintenance procedures generally include use of snow plows, deicing chemicals, and abrasives. The ability to analyze weather conditions and knowledge of the characteristics of each deicing chemical can increase efficient and effective usage of equipment, materials, and personnel. Deicing chemicals have specific temperature ranges and optimum application rates for maximum effectiveness. The efficiency and benefit of chemicals are greatly diminished when applications miss the correct temperature and quantity combination for each specific chemical. Abrasives, such as sand, are employed both with and without deicing chemicals depending upon temperature and conditions. Efficient usage not only saves money in material, labor, and equipment costs, but also gives the best results in fulfilling a particular road maintenance goal.²

Abrasives are used primarily to increase traction on slippery surfaces, but can stimulate some melting through solar energy absorption. In areas of high traffic or wind speed, sand can be blown off the roadway. Use of abrasives is generally undesirable in areas which utilize storm drainage systems. Due to retained moisture, stockpiled abrasives can freeze solid at cold temperatures, and this problem has led to the practice of adding deicing chemicals to abrasives not in sheltered storage.³

The most common deicing chemicals in use on roads are sodium chloride (NaCl) and calcium chloride (CaCl_2). Each operates within certain temperature ranges. The effective field temperature range is substantially higher than the laboratory determined eutectic point at which a saturated solution of the chemical will freeze. At low temperatures, greatly increased amounts of the chemicals are required to obtain a melting effect, and efficiency is eliminated. In practice, NaCl is usually not employed below 25° and CaCl_2 not below 20°F . The negative effects of these salts include corrosion of ferrous metals and related concrete spalling; stunted growth or death of roadside vegetation; and increased chloride levels in water supplies which pose a potential health hazard.

Because of the known harmful effects of salts, research has been conducted to find alternative chemical and physical solutions. A few substitute chemicals are discussed in this paper. Many alternative deicing agents exist; however, some may cause similar or more serious damage than salts. A few agents have been identified which are effective and cause minimal adverse effects; among these are calcium magnesium acetate (CMA), methanol, urea, tetrapotassium pyrophosphate (TKPP), ethylene glycol, and formamide.⁴ Urea and CMA were chosen as alternative deicing chemicals for use in this report because of proven or potential production capability in Alaska, effective temperature ranges similar to NaCl and CaCl₂, and minimal related environmental or corrosion damage.

Urea, which is currently utilized on airport runways in the Anchorage area, is known to be effective in a temperature range similar to CaCl₂ and is currently produced in Kenai, Alaska. Although urea can have some negative impact on vegetation and may cause slight concrete spalling, the harmful effects are much less than with NaCl or CaCl₂.⁵ It was not possible to quantify these effects for urea. Much of the potential vegetation damage from urea could be avoided simply by not exceeding amounts which can be absorbed by the vegetation as a fertilizer. Inclusion of costs from the negative effects of urea would not significantly alter the economic analysis results due to their small amount relative to the damage costs of salts.

CMA, although not yet proven in full-scale field use, has been the subject of extensive research by the Alaska Department of Transportation and Public Facilities. This research has indicated that CMA is non-corrosive, environmentally benign, and effective in a temperature range similar to NaCl. Studies also show that CMA could be economically produced from raw materials available in Alaska.⁶ One method of producing CMA utilizes calcium carbonate (limestone) and acetic acid. Limestone of an acceptable grade is found in accessible and large quantities in the northern Brooks Range, the southern Alaska Range, and the southern Wrangell Mountains.⁷ Acetic acid could probably be obtained from the petroleum industry and at significantly lower costs than from present sources. These factors could serve to reduce the estimated cost of CMA used in this analysis. The Alaskan limestone used in this process will yield calcium acetate rather than calcium magnesium

acetate; however, the term CMA will be used in this report. Field testing of locally produced CMA will be conducted by the Alaska Department of Transportation and Public Facilities during the 1983-1984 winter season.

Another chemical with potential for use in Alaska is methanol. A byproduct of CMA production, it appears to be an effective deicer and is non-corrosive. Environmental effects would be minimal as most of the methanol would evaporate. Alaska's cold temperatures reduce methanol's volatility and increase its safety and persistence on road surfaces. Lack of published information prevented the use of methanol in this report, but it appears to be an excellent candidate for additional research as a companion deicing agent with CMA.⁸

Table 1 presents a summary of the deicing chemicals considered in this analysis. For the purposes of this study, it was assumed that equivalent results would be produced by the use of CMA and urea in amounts equal to the current tonnage of NaCl and CaCl₂. In experimental tests, varying amounts of each chemical are required to melt a specific amount of ice at different temperatures. Slightly greater quantities of CMA (or urea) than NaCl (or CaCl₂) are generally required on an equiosmolar basis; however, field research is needed to determine appropriate and effective application rates for Alaska. Extremely large quantity increases of CMA and urea would be required to generate a total cost (materials plus damages) equal to that of NaCl and CaCl₂.

Table 1

DEICING CHEMICALS

	<u>Advantages</u>	<u>Disadvantages</u>
NaCl	<ul style="list-style-type: none">- works quickly when applied in solution- least expensive material cost	<ul style="list-style-type: none">- imported material- very corrosive- harmful to roadside vegetation and local drinking water
CaCl ₂	<ul style="list-style-type: none">- works at low temperatures- works quickly (reaction with water is exothermic)	<ul style="list-style-type: none">- imported material- very corrosive- harmful to roadside vegetation and local drinking water
Urea	<ul style="list-style-type: none">- Alaskan product- works at low temperatures similar to CaCl₂- acts to clean oils off the roads	<ul style="list-style-type: none">- harmful to roadside vegetation with frequent, heavy applications- expensive material cost
CMA	<ul style="list-style-type: none">- potential Alaskan product- corrosion inhibitor- effectiveness similar to NaCl indicated by extensive research- does not harm roadside vegetation or drinking sources- works in temperature range similar to NaCl	<ul style="list-style-type: none">- expensive material cost- no history of field use

3.0 EXISTING MAINTENANCE PROCEDURES

The study area for the data presented in this report includes roads within the Municipality of Anchorage, south from Anchorage on the Seward Highway to Milepost 75.2 (including the Ingram Creek Bridge), and north from Anchorage on the Glenn Highway to Milepost 32.0 (including the Matanuska River Bridge). Winter road maintenance is shared by the State of Alaska and the Municipality of Anchorage. Arterials to and from Anchorage and most major roads in the City are maintained by the State. The Municipality is responsible for the remainder of roads within Anchorage. Cost information on present maintenance programs was obtained from the State and Municipal maintenance departments responsible for the study area. For simplicity, all information from the two departments is presented in combined form and treated as one entity.

Presently, the State and Municipality together utilize approximately 4,200 tons of sodium chloride, 75 tons of calcium chloride, and 46,000 tons of sand in the study area per year. These numbers may vary slightly from year to year depending upon weather conditions. Because the sand is stored in unsheltered stockpiles, the primary use of sodium chloride is to prevent the sand from freezing; approximately 85% of the sodium chloride is presently used for this purpose. Both sodium and calcium chloride are also applied directly to road surfaces as deicing agents, and calcium chloride in solution is sometimes used for ice glazing conditions. The main sites for straight salt applications are curves, major intersections, the base of hills, and downtown areas. Sand application is generally avoided in the downtown area because the storm drainage system can become clogged by the heavy use of abrasives. As snow plowing is a major part of winter road maintenance and will continue to be part of the maintenance program regardless of the type of deicing chemicals used, costs related to plowing are not examined and are assumed to remain at current levels. Table 2 summarizes existing maintenance procedures for the study area.

Neither the State of Alaska nor the Municipality of Anchorage have promulgated a specific winter road maintenance policy. Reasons for this may include fear of litigation if the policy is not strictly adhered to in the field, lack of specific information on current maintenance practices, and apparent

satisfaction of the general public with current practices and road conditions. In a number of lower 48 "snow belt" states, increased public knowledge of the total costs of salt usage (environmental, vehicular, and structural damage) has generated pressure to reduce salt levels. Maintenance policies developed by these states usually outline procedures to follow in various weather conditions and set applications rates for deicing materials. These procedures have resulted in drastically decreased amounts of salt use - many times with no discernable decrease in maintenance acceptability.⁹

To date, the maintenance departments in the study area have operated autonomously and, it should be added, effectively. The emphasis has been upon doing whatever is necessary to clear the roads. Without any incentive to question the efficiency of operations, evaluation of rates and timing of salt applications has not occurred. Examination of application rates reveals that present practices are very inexact. This is in part due to the type of equipment utilized, which is not calibrated to adjust to various speeds, and to the lack of information on correct application rates for Alaska. In comparison to rates utilized in other areas of the country, the application rates for salt used here are quite high. Acceptable ice melting results can be obtained with reduced and more efficient application rates.¹⁰ This example is presented as an illustration of the present deicing program in the study area and to show that excessive amounts of salts are employed. The assumption that substitution of CMA and urea in amounts equal to the NaCl and CaCl₂ presently used will result in equivalent road conditions is based in part upon this over-application. Field testing is needed to determine efficient application amounts which will maintain the desired road conditions in Alaska.

Table 2
SUMMARY OF EXISTING MAINTENANCE PROCEDURES

Direct Salt Applications:

NaCl: Temperature range - upper 20's°F and above. Used in mixture 5% by volume NaCl to sand and in straight application to roads. 85%± of total tonnage used per year is mixed with stockpiled sand.

CaCl₂: Temperature range: - down to 20°F. Used in straight dry applications to roads and in solution on glaze ice.

Sand: Used at hills, curves, and intersections. Not used on snow occurring at temperatures near 30°F (generally the first and last snows of the season).

Application Rates

Salt: Truck feeder door open 2"±, speed: 15-20 mph.

Sand: Truck feeder door open 4"±, speed: streets 15-25 mph, highway 25-30 mph.

4.0 ECONOMIC ANALYSIS

The economic analysis presented considers not only direct material costs, but also indirect costs incurred through the use of corrosive deicing salts. Four deicing programs are examined in terms of total cost, which includes direct and indirect costs. These programs are: 1) the use of NaCl, CaCl_2 and sand at present levels; 2) equal quantity substitution of CMA and urea for NaCl and CaCl_2 with sand use at present levels; 3) stockpile sand in heated storage buildings and reduce the amount of NaCl and CaCl_2 ; and 4) stockpile sand in heated storage buildings and use reduced amounts of CMA and urea. The programs are presented in these combinations so that the benefits resulting from use of substitute chemicals and of heated sand storage can be examined separately.

Certain assumptions and simplifications were necessary to make the economic analysis possible. The basis for most of these assumptions, listed in Table 3, has been presented in the preceding discussion. Interpretation of existing data, conversations with experts, and engineering experience were used to develop the assumptions. This paper is a pragmatic attempt to deal with complex chemical, physical and economic elements; as more research is conducted, many of the questions raised by this paper will be answered. One known fact is that salt damages the environment, vehicles, and bridges.

The procedures used to develop estimates for vehicle value loss due to corrosion, costs of bridge deck damage, and costs of heated sand storage are presented in Sections 4.1, 4.2, and 4.3 respectively. These estimates are then added to the materials costs of the appropriate program, and all costs are brought to an annual basis for comparison purposes. Costs, when possible, are based upon actual costs in the Anchorage area, which are subject to minor changes. The relative differences between the total costs of the four programs are not likely to be affected by annual fluctuations in material costs and weather conditions.

Table 3
ASSUMPTIONS

- Proposed alternate deicing programs will maintain the present level of road conditions.
- Storage of sand in heated buildings will eliminate 85% of NaCl use.
- Heat retained in the sand will prevent freezing of sand in the trucks and will cause the sand to adhere to the road surface. This eliminates the need for any salt in the sand.
- Calcium magnesium acetate (CMA) is an equivalent substitute for NaCl given current application procedures.
- Urea is an equivalent substitute for CaCl_2 given current application procedures.
- NaCl and CaCl_2 are equally corrosive per ton.
- Use of CMA and urea would eliminate damage to vehicles and bridge decks.
- Vehicle damage costs due to corrosion will be reduced in proportion to the reduction in use of corrosive deicing chemicals (specifically NaCl and CaCl_2).
- Bridge deck repair costs due to corrosion will be reduced in proportion to the reduction in use of corrosive deicing chemicals (specifically NaCl and CaCl_2).

4.1 VEHICLE VALUE LOSS DUE TO CORROSION

The estimated loss of vehicle value due to corrosion damage is based upon approximate repair costs and the particular vehicle population in the study area. According to data from the State of Alaska Department of Motor Vehicles, approximately 80% of registered vehicles in the Anchorage/Eagle River area are at least 6 years old and about 30% of registered vehicles are pickup trucks. As of 1982, registered vehicles in the study area numbered approximately 167,000.

VEHICLE POPULATION IN STUDY AREA*

	<u>6 Yrs. or Older</u>	<u>Total in Study Area</u>
Cars	94,000	117,000
Trucks	<u>40,000</u>	<u>50,000</u>
Total	134,000	167,000

*State of Alaska Department of Motor Vehicles

Major repair costs due to corrosion were predicted by local insurance claims adjusters. The two individuals consulted have approximately 50 years combined experience, primarily in Anchorage, and have seen firsthand the effects and extent of corrosion damage in vehicles of all types and ages. From their observations, they predict that many vehicles show signs of corrosion after 3 years and that repairs are generally needed after 6 years.

Required repairs for this analysis are defined as the work necessary to restore a vehicle to a condition similar to its appearance in the first year of use. Only damage from corrosion is considered; no collision or other damage is included. All older cars were considered to have the same requirements predicted for those six years old while younger vehicles were assumed to have no damage. Vehicle design causes some cars to be more

susceptible to corrosion and others less so; however, this factor was considered to be negligible when examining the total vehicle population. Since trucks comprise a sizable portion of the study area vehicle population and have different repair costs, trucks and passenger cars are costed separately. In the experience of the insurance claims adjustors consulted, proportionately more trucks are susceptible to rust attack than passenger cars; this factor is reflected in the economic analysis by the percentage of car or truck population used to calculate repair costs. Using vehicle population data and predicted repair costs, an average vehicle repair cost per year is derived.

Since most people prefer to sell a vehicle rather than incur repair costs, reduction in resale value rather than repair cost is a better indication of actual cost to the public due to corrosion. Resale value, however, is based upon a number of variables which are beyond the scope of available data and this report, so repair costs were used as an alternate value determinant because they are easier to estimate and predict. Value loss was estimated to be approximately equivalent to 50% of the repair costs. Costs of preventative measures such as factory undercoatings or commercial rust treatments are not included in this analysis but do represent a direct cost to vehicle owners. All costs included in the analysis are based on conservative estimates and, as such, represent the lower end of actual damages.

Estimated Vehicle Repair Costs

Trucks - Trucks 6 yrs. or older in study area = 40,000
At year six, 20% of all trucks in the study area will require the following repairs:

Repair side panel (\$785/side)	\$ 1,570
Replace fender (\$385/side)	<u>770</u>
	\$ 2,340

20% of trucks six years and older will have repair costs of \$2,340 =

20% x 40,000 x \$2,340 = **\$18,720,000 Total Truck Repair Costs**

Cars - Cars 6 yrs. or older in study area = 94,000
At year six, 15% of all cars in the study area will require the following repairs:

Replace fender (\$405/side)	\$ 810
Replace quarter panel (\$895/side)	1,790
Repair door w/splice (\$210/side)	<u>420</u>
	\$ 3,020

15% of cars six years and older will have repair costs of \$3,020 =
 $15\% \times 94,000 \times \$3,020 = \$42,582,000$ Total Car Repair Costs

**Total car and truck repair costs for
vehicles six years and older = \$61,302,000**

$\$61,303,000 \div 6$ (age of damaged vehicles) = **\$10,217,000 Annual Repair Costs**

Average value loss per year is approximately 50% of the repair costs, thus:

$\$10,217,000 \times 50\% = \$5,108,500$

or

Approximate Vehicle Value Loss = \$5,100,000 Annually

Census bureau predictions show substantial increases in the Anchorage vehicle population in the future. If present maintenance policies continue, salt related damage costs to vehicles will increase as the number of vehicles increase. By applying the same process used on the 1982 vehicle population to populations projected for years 1990 and 2000, an estimate of the damage costs to vehicles which will be incurred can be made.

Estimated Vehicle Value Loss

<u>Year</u>	<u>1982</u>	<u>1990</u>	<u>2,000</u>
Vehicle Population	167,000	212,650	260,350
Annual Vehicle Value Loss (in 1983 \$)	\$ 5,100,000	\$ 6,500,000	\$ 8,000,000

Given current maintenance practices, the average vehicle owner in the Anchorage area faces repair costs of approximately \$3,000 to restore a 5 or 6 year old car to near-new appearance based solely on corrosion damage. The amount of corrosion damage to a particular vehicle depends upon many factors such as design, maintenance, driving conditions, and climate, but corrosion causes significant damages to most cars. The repair costs used in this analysis are based on conservative estimates of damage, repair needs, and repair costs.

The problems posed by salt usage will not disappear, but rather will increase with time. Although an expanded roadway system and population increases do not necessarily mean an increase in the amount of corrosion on an individual vehicle, increases in the total program cost would result from the larger vehicle population experiencing corrosion and the materials cost of the increased salt tonnage needed to treat the expanded road surface area.

4.2 BRIDGE DECK REPAIR COSTS DUE TO CORROSION

To obtain a general cost per year due to the use of corrosive deicing chemicals for bridge decks, the average cost per square foot of repairs to the average reinforced concrete bridge deck were considered. The reinforced concrete design (termed "basic design" in this report) is most representative of existing bridges in the study area. Several modified designs which can reduce or prevent corrosion related damage are examined in Appendix B. Only the costs for existing bridge decks (basic design) are included in the total cost analysis.

Costs per square foot for the various situations were calculated based upon expected maintenance and repair needs due to corrosion. Similar construction projects in Anchorage and Fairbanks were used to generate the unit costs presented in Table 4. Costs common to all alternatives have no effect on the evaluation and were excluded, including original construction costs for a standard reinforced concrete bridge deck, annual maintenance, and replacement of the asphalt wearing course every 15 years. By eliminating these common costs, the additional costs due to corrosion are isolated. The cost per square foot for the standard bridge design type can be used to approximate the hidden costs due to repairing or avoiding corrosion damage. Multiplying by the total square footage of bridge deck in the study area yields the hidden cost used in the program cost analysis. Utilizing the Alaska Highways Bridge Inventory Report - 1980 prepared by the State of Alaska Department of Transportation and Public Facilities - Bridge Design Section, the total bridge deck surface in the study area was determined to be approximately 620,000 square feet. This includes various bridge structure types but all have reinforced concrete decks.

Although not fully determined, it appears that annual maintenance costs are reduced with the use of a bituminous membrane and asphalt wearing course. This would increase the costs of any design not using these techniques, i.e. many existing bridges. No specific cost data was available on this subject, thus annual maintenance costs are not included. As stated earlier, corrosion damage is assumed to be proportional to the amount of salts used. If the amount of NaCl and CaCl_2 used is reduced by a certain percentage, the damage costs to bridge decks will be reduced by the same percentage.

A standard engineering economic evaluation known as equivalent uniform annual cost (EUAC) was used to generate an annual cost for bridge deck damage resulting from the use of deicing salts. The EUAC provides a basis of comparison for the various maintenance programs. All costs, initial and future, can be converted to units of equivalent cost through this evaluation process, and the formulas used for computing EUAC are given in Appendix A. The EUAC 's of future and present costs are affected by the value of capital which is represented by the prevailing interest rate adjusted for inflation. The interest rate chosen for this comparison is 7% and does not include an inflation rate because all costs presented are in real 1983 dollars.

Equivalent Uniform Annual Costs of Bridge Repairs

Basic Design - Unprotected Reinforcing

Year 15 - Repair and patch concrete deck (\$1.50/ft.²) and install bituminous membrane (\$2.25/ft.²).

Year	0	15	30
Costs		1.5/ft. ² 2.25/ft. ²	

(15 year life is optimistic prior to installation of bituminous membrane)

Equivalent Annual Cost = \$0.1095/sq.ft.

This analysis of bridge deck costs to repair corrosion damage yields the following:

$$620,000 \text{ ft.}^2 \times \$0.1095/\text{ft.}^2 = \$67,890/\text{yr.}$$

or

Approximate Damage Costs to Existing Bridge Decks = \$68,000 Annually

Table 4

UNIT COSTS USED IN ANALYSIS

	<u>Cost/ft.²</u>	<u>Design Type</u>
Future Costs	\$ 1.50	Patching - includes removal and replacement of damaged concrete and repair of damaged reinforcing steel.
	2.25	Initial installation or replacement of bituminous membrane, must be replaced every 15 years.
Present Costs	1.50	Epoxy coated or galvanized reinforcing (additional cost of epoxy coating or galvanizing over the steel material cost).
Present and Future Costs	5.10	Installation of impressed current cathodic protection system (C.P.). System must be replaced every 15 years.
Annual Costs	.20	Annual power costs for impressed current cathodic protection system.

4.3 SAND STORAGE BUILDING COSTS

Presently, both State and Municipal maintenance departments must mix NaCl in their sand stockpiles to keep the materials workable at low temperatures. This procedure accounts for approximately 85% of the total NaCl presently used, and by stockpiling sand in heated storage buildings, the major use of NaCl can be eliminated.

In addition to preventing freezeup of the sand stockpiles, the NaCl in the sand may have a residual melting effect on the roadway and help reduce the amount of sand blown off the road by vehicles and/or wind. The same effect could result from heat absorbed by sand in a heated building. Research is currently being conducted to test this hypothesis. Preliminary information received from this research indicates that the sand must be heated to 200°F to obtain adherence to the roadway. Processes similar to those used in asphalt mixing would be an effective way to heat the sand prior to distribution, and infrared heaters in the storage buildings might be an effective way to both prevent freezing and store heat in the sand. Heat loss while in the distribution trucks could be greatly reduced through the use of insulated liners and covers. With use of the heated storage buildings, an 85% reduction in NaCl use is possible.

Given that the present level of sand use would remain the same, approximately 50,000 sq.ft. are needed to house 15± foot high stockpiles. Increasing the square footage by 20% will accommodate equipment required to handle the sand. Storage space of 60,000 sq.ft. at a cost of \$60.00 per sq.ft. would provide a simple, heated and insulated storage structure on a gravel foundation. It is assumed that the building(s) will be built on land currently used for sand storage, and land acquisition costs are not included. Through utilization of specialized bulk storage construction, the footage requirements and construction costs might be reduced; however, adequate insulation of these specialized building types for use in Alaska would probably place them on a par with the costs presented here. This facility would have a construction cost of approximately \$3,600,000 and maintenance/operations costs of around \$100,000 annually. The construction cost is amortized over a 30-year structure life for purposes of this analysis

to give a \$120,000/year cost. Addition of maintenance and operations costs gives a \$220,000 annual cost for the heated sand storage space.

4.4 COST ANALYSIS

The cost analysis is based upon the present road maintenance program and the alternatives previously discussed. Costs include materials, loss of vehicle value, and average bridge deck repair costs. The following maintenance programs are examined: A) present maintenance program using NaCl, CaCl₂, and outdoor stockpiled sand, B) substitution of CMA and Urea for NaCl and CaCl₂ with outdoor stockpiled sand, C) use of NaCl and CaCl₂ with heated sand storage buildings, and D) use of CMA and Urea with heated sand storage buildings. Individual cost breakdowns are presented with a summary of the total costs of each program.

Table 5

COST ANALYSIS

A. NaCl, CaCl₂, Sand - Present Level

NaCl (4,200 tons @ \$86)	\$ 360,000
CaCl ₂ (75 tons @ \$370)	28,000
Sand (46,000 tons @ \$7)	<u>322,000</u>

Subtotal \$ 710,000

Vehicle Value Loss	5,100,000
Bridge Deck Cost	<u>68,000</u>

Total Cost \$ 5,878,000/yr.

B. Substitute Chemicals (Present Levels) CMA, Urea, Sand

CMA (4,200 tons @ \$500)	\$ 2,100,000
Urea (75 tons @ \$200)	15,000
Sand (46,000 @ \$7)	<u>322,000</u>

Total Cost \$ 2,437,000/yr.

C. Heated Storage Buildings, Sand, Reduced Amounts of NaCl, CaCl₂, Sand

NaCl (630 tons @ \$86)	\$ 54,000
CaCl ₂ (75 tons @ \$370)	28,000
Sand (46,000 tons @ \$7)	322,000
Buildings	<u>220,000</u>

Subtotal \$ 624,000

Vehicle Value Loss	765,000
Bridge Deck Cost	<u>10,000</u>

Total Cost \$ 1,399,000/yr.

D. Heated Storage Buildings, Sand, Reduced Amounts of CMA and Urea

CMA (630 tons @ \$500)	\$ 315,000
Urea (75 tons @ \$200)	15,000
Sand (46,000 tons @ \$7)	322,000
Buildings	<u>220,000</u>

Total Cost \$ 872,000/yr.

Table 6

COST ANALYSIS SUMMARY - ANNUAL COSTS

<u>Program</u>	<u>Direct Costs</u>	<u>Damage Costs</u>	<u>Total Cost</u>
A. Present Levels - NaCl, CaCl ₂ , Sand	\$ 710,000	\$ 5,168,000	\$ 5,878,000/yr.
B. Substitute Chemicals - CMA, Urea, Sand	\$ 2,437,000	\$ 0	\$ 2,437,000/yr.
C. Reduced Amounts of NaCl and CaCl ₂ , Heated Sand Storage Buildings	\$ 624,000	\$ 775,000	\$ 1,399,000/yr.
D. Reduced Amounts of Urea and CMA, Heated Sand Storage Buildings	\$ 872,000	\$ 0	\$ 872,000/yr.
Loss of Vehicle Value:			\$5,100,000/year
Bridge Deck Repairs:			\$68,000/year
Heated Storage Buildings:			\$220,000/year

5.0 CONCLUSIONS AND RECOMMENDATIONS

Inclusion of costs to the public from damages to vehicles and bridge decks, totalling approximately \$5,168,000 per year in the study area, drastically changes the picture for deicing salts. These materials have traditionally been considered the cheapest means to effective winter road maintenance because of their low material costs. Calculation of damages related to the use of sodium and calcium chlorides provides the basis for utilization of alternatives with apparent higher direct costs but with reduced damaging effects. As shown by the Cost Analysis Summary on the preceding page, the apparent or direct costs utilized in the past are very misleading in terms of the total cost picture.

Examination of this total picture has probably not occurred previously due to the nature of the indirect costs. The money for deicing programs, road maintenance, and vehicle damage seems to come from different pockets or at least different departments. In reality, all the costs are borne by the public in the end. Because of the funding methods for the affected government maintenance programs, changes to the status quo will require a policy decision at the administrative level. It would be very difficult for the local maintenance manager to justify increased direct expenses solely on the basis of alleviating costs to individual citizens in his maintenance area. The maintenance manager's recognized concerns are solely considered to be maintaining safe conditions on the roads at the lowest cost. What must be recognized is that the lowest cost to the public is not synonymous with the lowest maintenance and operations program costs.

Public education and awareness of the total costs of road salting will be a necessary precursor to major policy changes. If situations in some lower-48 snowbelt states are an example, an educated public will support policy changes to reduce their cost burden. As mentioned numerous times, a great deal of additional research is needed to more exactly quantify costs and verify the assumptions used. The costs and assumptions presented are based on conservative interpretations of present practices and available research.

Even with the need for future research, the magnitude of cost differences strongly indicates that some alternate measures can be justified right now. The most obvious is the construction and use of sand storage buildings. Other immediate possibilities include monitoring of chemical application rates to optimize effectiveness, better calibration of distribution equipment, increased education of maintenance managers and truck operators on the characteristics of chemicals and procedures for specific weather conditions, and development of official standard winter road maintenance policies. An important consideration in implementation of these suggestions is that the person on-site and in-the-field is the best judge of the situation. The more knowledgeable that person is, the more effective and efficient maintenance efforts will be. A multitude of examples for procedures and programs exist in other states and their past experience should prove beneficial to Alaska.

Although some policy and personnel procedures can be applied to Alaska, testing of field techniques must be conducted under our severe climate conditions. This is particularly true for examining alternate deicing chemicals and determining application rates for the materials presently utilized. Research is currently being conducted on CMA and on the benefits of using heated sand. This should provide answers to some of the issues raised in this analysis. Research efforts should continue in order to identify the best method for providing acceptable winter road conditions for the lowest possible total cost. In the meantime, information on the total cost of present winter road maintenance procedures should be presented to the general public, and all means possible should be employed to reduce the needless damage and cost incurred through the use of corrosive deicing chemicals.

APPENDIX A
SUMMARY OF CONVERSATIONS

INDIVIDUAL

COMMENTS

Claims department manager
of a major insurance
company in Anchorage

- Corrosion on automobiles in Anchorage was minimal up to 1973. Since then it has increased significantly.
- The average car insurance premium for liability is increased approximately \$3-4/premium due to corrosion.
- If the present rate of damage to automobiles by corrosion continues, the structural integrity of new model cars with unibody construction may be jeopardized by corrosion damage.
- Car dealers in Anchorage generally do not buy or trade cars with visible rust.

Auto-body damage estimator
with 28 years of experience
in the Anchorage area

- Corrosion damage to automobiles in Anchorage is increasing.
- 35% of cars show signs of corrosion after 3 years.
- Some local car washes recirculate water laden with road salt which was washed from previous cars.

INDIVIDUAL

COMMENTS

- The depreciation of an automobile's monetary value due to corrosion is usually less than the repair cost to eliminate the corrosion. Most corrosion damage to a vehicle is passed on to a new owner, and the vehicle is used until it is no longer serviceable.
-
- | | |
|--|---|
| Alaska DOT&PF area
maintenance manager | <ul style="list-style-type: none">- NaCl is used primarily for mixing with the sand to keep the sand from freezing into unworkable piles in the winter season.- NaCl is used directly on the roads as a deicing agent usually in the early spring when temperatures are at or near freezing.- Sanding is avoided in the downtown area of Anchorage to keep sand out of the storm drains.- Liquid CaCl_2 is used for ice fog conditions, i.e. glazing conditions. |
| President of local towing
and wrecking yard | <ul style="list-style-type: none">- Cars experience more corrosion damage in Anchorage than in the Seattle area. |
| Airport maintenance foreman | <ul style="list-style-type: none">- As with all deicers, urea works best as a preventative against icing.- Urea will work instantly at 20°F and up. |

INDIVIDUAL

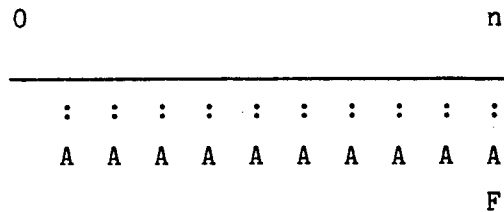
COMMENTS

- Urea harms vegetation alongside the runways.
This occurs after frequent applications of high dosage. (Runways require a higher level of maintenance than roads, and applications would be less frequent on roadways.)
- Urea acts as a detergent to clean the runways of oil products.
- Urea pellets are applied straight with no modifications required to the sanding trucks.

APPENDIX B
EQUIVALENT UNIFORM ANNUAL COST FORMULAS

i = interest rate per interest period (7% per year used in this report)
 n = number of interest periods
 P = a present sum of money
 F = a future sum of money
 A = an end-of-period cash receipt or disbursement in a uniform series continuing for n periods, the entire series equivalent to P or F at interest rate of $i\%$

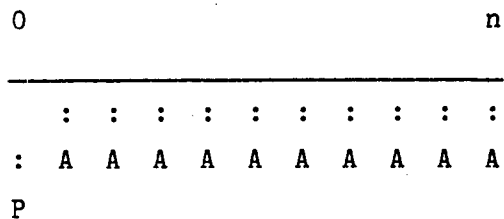
To Find a Given F



To find A given F , (A/F , $i\%$, n):

$$A = F \times \frac{i}{(1 + i)^n - 1}$$

To Find A Given P



To find A given P , (A/P , $i\%$, n):

$$A = P \times \frac{i (1 + i)^n}{(1 + i)^n - 1}$$

APPENDIX C ALTERNATE BRIDGE DESIGN COSTS

The following two modified designs are calculated in terms of EUAC for comparison purposes. These are costs which could be incurred as a result of avoiding or preventing corrosion damage. These and other techniques are used in many bridges built today. The small increase in cost from use of protected reinforcing steel in design #2 might be offset when the costs of annual maintenance in the first 15 years of the standard design are calculated and included.

Modified Design with Epoxy Coated Reinforcing Steel

Year 0 - Additional cost of protected reinforcing ($\$1.50/\text{ft.}^2$).

Year 15 - Install bituminous membrane ($\$2.25/\text{ft.}^2$).

Year	0	15	30
Costs	1.5 ft. ²	2.25/ft. ²	
Equivalent Annual Cost = $\$0.1866/\text{sq.ft.}$			

Modified Design with Cathodic Protection

Year 0 - Install impressed current cathodic protection system (C.P.) ($\$5.10/\text{ft.}^2$).

Year 15 - Replace C.P. system ($\$5.10/\text{ft.}^2$).

Year 1 to 30 - Annual power costs ($\$.20/\text{ft.}^2$).

Year	0	15	30
Costs	5.1/ft. ²	Annual cost = $\$0.2/\text{ft.}^2$ 5.1/ft. ²	
Equivalent Annual Cost = $\$0.76/\text{sq.ft.}$			

FOOTNOTES

¹Donald Murray and Ulrich Ernst, An Economic Analysis of the Environmental Impact of Highway Deicing, U.S. Environmental Protection Agency, ERA Report No. 600/2-76/105, pp. 1-4.

²State of the Art in Road Salt Deicing 1982, National Park Service Water Resources Field Support Laboratory Report No. 82-3, September 1982.

³Ibid., p. 7.

⁴Alternative Highway Deicing Chemicals, Federal Highway Administration Report No. FHWA-RD-79-108, March 1980.

⁵Ibid., pp. 25-34.

⁶Ibid., pp. 18-25.

⁷Gary Arce, The Distribution of Carbonate Deposits Along Alaska's Roads, July 1983.

⁸Alternative Highway Deicing Chemicals, p. 25.

⁹Minimizing Deicing Chemical Use, Transportation Research Board, National Cooperative Highway Research Program Synthesis 24, 1974.

¹⁰Ibid.

Note: These footnotes indicate particular data sources. Much of the information presented was synthesized from numerous sources, and the bibliography citations should be consulted for a more comprehensive understanding of the subject.

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